

10/25/00
JC772 U.S. PTO

Patent
Attorney's Docket No. 030681-248

JC932 U.S. PTO
09/695253
10/25/00

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

UTILITY PATENT
APPLICATION TRANSMITTAL LETTER

Box PATENT APPLICATION

Assistant Commissioner for Patents
Washington, D.C. 20231

Sir:

Enclosed for filing is the utility patent application of (1) Hang-woo LEE, (2) Nae-sung LEE, (3) Yong-soo CHOI, and (4) Jong-min KIM for TRIODE FIELD EMISSION DISPLAY USING CARBON NANOTUBES.

Also enclosed are:

- ☒ 3 sheet(s) of ☒ formal ☐ informal drawing(s);
- ☒ a claim for foreign priority under 35 U.S.C. §§ 119 and/or 365 is ☒ hereby made to 00-9394 filed in Korea on February 25, 2000;
- ☒ in the declaration;
- ☒ a certified copy of the priority document;
- ☐ a General Authorization for Petitions for Extensions of Time and Payment of Fees;
- ☒ an Assignment document;
- ☐ an Information Disclosure Statement; and
- ☐ Other: _____
- ☒ An ☒ executed ☐ unexecuted declaration of the inventor(s)
- ☒ also is enclosed ☐ will follow.
- ☒ Please amend the specification by inserting before the first line the sentence --This application claims priority under 35 U.S.C. §§ 119 and/or 365 to 00-9394 filed in Korea on February 25, 2000; the entire content of which is hereby incorporated by reference.--
- ☐ A bibliographic data entry sheet is enclosed.
- ☐ Small entity status is hereby claimed.



21839

☒ The filing fee has been calculated as follows [] and in accordance with the enclosed preliminary amendment:

CLAIMS					
	NO. OF CLAIMS		EXTRA CLAIMS	RATE	FEE
Basic Application Fee					\$710.00 (101)
Total Claims	2	MINUS 20 =	0	× \$18.00 (103) =	0
Independent Claims	2	MINUS 3 =	0	× \$80.00 (102) =	0
If multiple dependent claims are presented, add \$270.00 (104)					0
Total Application Fee					\$710.00
If small entity status is claimed, subtract 50% of Total Application Fee					0
Add Assignment Recording Fee \$ if Assignment document is enclosed					\$ 40.00
TOTAL APPLICATION FEE DUE					\$750.00

- ☐ This application is being filed without a filing fee. Issuance of a Notice to File Missing Parts of Application is respectfully requested.
- ☒ A check in the amount of \$ 750.00 is enclosed for the fee due.
- ☐ Charge \$ _____ to Deposit Account No. 02-4800 for the fee due.
- ☒ The Commissioner is hereby authorized to charge any appropriate fees under 37 C.F.R. §§ 1.16, 1.17 and 1.21 that may be required by this paper, and to credit any overpayment, to Deposit Account No. 02-4800. This paper is submitted in duplicate.

Please address all correspondence concerning the present application to:

Charles F. Wieland III
BURNS, DOANE, SWECKER & MATHIS, L.L.P.
P.O. Box 1404
Alexandria, Virginia 22313-1404.

Respectfully submitted,

BURNS, DOANE, SWECKER & MATHIS, L.L.P.

Date: October 25, 2000

P.O. Box 1404
Alexandria, Virginia 22313-1404
(703) 836-6620

By: 

Charles F. Wieland III
Registration No. 33,096

TRIODE FIELD EMISSION DISPLAY USING CARBON NANOTUBES

BACKGROUND OF THE INVENTION

1. Field of the Invention

5 The present invention relates to a triode field emission display using carbon nanotubes having an excellent electron emission characteristic.

2. Description of the Related Art

10 In a conventional field emission display (FED), when a strong electric field is applied through gates to a Spindt's field emitter array (FEA), which is formed of a metal such as molybdenum (Mo) or a semiconductor material such as silicon (Si), that is, to microtips arranged at regular intervals, electrons are emitted from the microtips. The emitted electrons are accelerated toward anodes, to which voltage (for example, several hundred to several thousand volts) is applied, and collide with phosphors with which the anodes are coated, thereby emitting light. Because the work function of a metal or a semiconductor material used for the microtips of a conventional FED is large, the gate voltage for electron emission must be very high. Residual gas particles in vacuum collide with electrons and are thus ionized. Because the microtips are bombard with these gas ions, the microtips as an electron emission source may break. Moreover, since particles are separated from the phosphors colliding with electrons and pollute the microtips, the performance of the electron emission source may be deteriorated. These problems may reduce the performance and life of the FEA. To overcome these problems, instead of a metal or a semiconductor material, carbon nanotubes having a low electron emission voltage and an excellent chemical stability is used for microtips. In this case, the performance and life of the FEA can be improved.

25 Arc discharge and laser ablation is widely used in deposition of carbon nanotubes, but these methods are not suitable for mass production of carbon nanotubes at a low cost, and structure control is difficult in these methods. To

overcome these problems, vapor deposition has been developed. Representative vapor deposition methods include thermal chemical vapor deposition (CVD) (Appl. Phys. Lett. 67, 2477, 1995), MPECVD (Appl. Phys. Lett. 72, 3437, 1998) and ion beam irradiation (Appl. Phys. Lett. 69, 4174, 1996).

While the electron emission electrical field of a diamond film, which has been highlighted as a material of an electron emission source, is about $10 \text{ V}/\mu\text{m}$, carbon nanotubes have a characteristic in which electrons are easily emitted even at an electrical field of $1 \text{ V}/\mu\text{m}$ or less. Accordingly, carbon nanotubes have been touted as the next generation material of an electron emission source.

FIG. 1 is a schematic sectional view illustrating the structure of a conventional FED using carbon nanotubes. As shown in FIG. 1, the conventional FED using carbon nanotubes includes a front substrate 1 and a rear substrate 6 which face each other, an anode 2 and a cathode 5 which are formed on the surfaces of the two substrates 1 and 6 facing each other, respectively, phosphor 3 with which the anode 2 is coated, and carbon nanotubes 4 with which the cathode 5 is coated, thereby having a diode structure. A power supply 7 is applied between the anode 2 and the cathode 5.

It is crucial to deposit carbon nanotubes on a wide area at a low cost using a method capable of controlling the carbon nanotubes in manufacturing FEDs using carbon nanotubes. It is considered that vapor deposition should be used to achieve the above purpose. Similarly to arc discharge or laser ablation, vapor deposition uses a transition metal such as nickel (Ni) or iron (Fe) or silicide such as CoSi_2 as a catalyzer. Carbon nanotubes are not deposited on a structure of a predetermined pattern but have still been deposited randomly as in a diode structure. The diode structure can easily be manufactured by vapor deposition because a layer such as an insulating layer or a gate shown in a triode structure is not necessary. However, it is difficult to control emitted electrons in a simple diode structure. This disturbs the smooth performance of a display.

A field emitter using controlled carbon nanotubes is disclosed in U.S. Patent No. 5,773,834. In this patent, a field emitter is formed in a triode structure using a grid of a net shape as gate electrodes so that emitted electrons can be easily

controlled. However, the structure of the field emitter is not simple enough to be easily manufactured by vapor deposition like a diode structure.

SUMMARY OF THE INVENTION

To solve the above problem, an object of the present invention is to provide a triode field emission display (FED) using carbon nanotubes, which has a simple triode structure similar to a diode structure in which control of emitted electrons is easy, thereby allowing deposition of carbon nanotubes on a wide area at a low cost.

To achieve the above object, the present invention provides a triode FED using carbon nanotubes, which includes front and rear substrates disposed to face each other and separated by a predetermined distance, a cathode formed on the rear substrate, carbon nanotubes formed on the cathode, an anode formed on the front substrate, phosphor formed on the anode, and an extraction electrode formed on the front substrate on which the anode is formed, the extraction electrode being separated from the anode by a predetermined distance.

In another aspect, the present invention provides a triode FED using carbon nanotubes, which includes front and rear substrates disposed to face each other and separated by a predetermined distance, cathode lines formed on the rear substrate in a striped pattern, carbon nanotubes formed on the cathode lines at regular intervals, anode lines formed on the front substrate in a striped pattern crossing the cathode lines, phosphor formed on the anode lines, and extraction electrodes formed on the front substrate on which the anodes are formed, each extraction electrode being separated from each adjacent anode by a predetermined distance, the extraction electrodes being formed in a striped pattern parallel to the anode lines.

BRIEF DESCRIPTION OF THE DRAWINGS

The above object and advantage of the present invention will become more apparent by describing in detail preferred embodiments thereof with reference to the attached drawings in which:

FIG. 1 is a schematic sectional view of a conventional diode field emission display (FED) using carbon nanotubes;

FIG. 2 is a schematic sectional view of a triode FED using carbon nanotubes according to the present invention;

FIG. 3 is a graph illustrating the results of simulation of traces of electrons emitted from carbon nanotubes at an anode voltage of 0 V depending on the fixed extraction voltage in the triode FED of FIG. 2;

FIG. 4 is a graph illustrating the results of simulation of traces of electrons emitted from carbon nanotubes at an anode voltage of 700 V depending on the fixed extraction voltage in the triode FED of FIG. 2; and

FIG. 5 is a graph illustrating anode volt-ampere characteristic curves of diode and triode carbon nanotube FEDs depending on the change in extraction voltage.

DETAILED DESCRIPTION OF THE INVENTION

Referring to FIG. 2, a triode field emission display (FED) of the present invention is formed by depositing carbon nanotubes having an excellent electron emission characteristic on an anode using vapor deposition and disposing extraction electrodes acting as gates around the anode on the same surface as that on which the anode is formed. Accordingly, the triode FED of the present invention has a triode electron emission structure.

As shown in FIG. 2, a conductive cathode line 15 is formed of a transparent electrode or metal on a rear glass substrate 16. Carbon nanotubes 14 are disposed on the cathode line 15. Extraction electrodes 21 are disposed on a front glass substrate 1 to excite and make the carbon nanotubes 14 emit electrons. An anode 12 is coated with phosphor 13 and disposed between the extraction electrodes 21. In this structure, when a certain voltage V_e for extracting electrons from the carbon nanotubes 14 is applied to the extraction electrodes 21 and an anode voltage V_a is changed, traces of electrons, as shown in FIGS. 3 and 4, are obtained. These traces of electrons are the result of simulation.

FIG. 3 shows the traces of emitted electrons when an anode voltage is 0 V. It can be seen that electrons emitted from carbon nanotubes are dispersed toward extraction electrodes since the anode voltage is lower than the voltage (400 V) of the extraction electrodes. FIG. 4 shows the traces of emitted electrons when an anode voltage is 700 V. It can be seen that electrons emitted from carbon

nanotubes collected more toward the anode since the anode voltage is higher than the voltage (400 V) of the extraction electrodes. It is noted from these results that the amount of electrons colliding with phosphor on an anode can be controlled by controlling the voltage applied to extraction electrodes.

5 Actually, FIG. 5 proves this conclusion. FIG. 5 is graph showing the emission characteristic of a triode FED which was actually manufactured according to an embodiment of the present invention, as shown in FIG. 2. FIG. 5 shows the values of anode current depending on anode voltage with respect to a voltage V_e applied to extraction electrodes. When the voltage V_e applied to extraction electrodes is increased from 400 V by 50 V each time, such as 450 V and 500 V, the anode current depending on the anode voltage shows the typical voltage-current characteristic curves of a triode structure. Referring to FIG. 5, as the anode voltage is increased, the anode current increases. In addition, as the voltage V_e of the extraction electrodes is increased, emitted electrons are dispersed more toward the extraction electrodes. Consequently, the anode current decreases.

10
15
20 As described above, by forming extraction electrodes for controlling emitted electrons around an anode on a front substrate, a triode FED using carbon nanotubes according to the present invention has a simple structure like a diode FED, thereby facilitating manufacture using vapor deposition of carbon nanotubes and allowing control of anode current using extraction electrodes. Therefore, the present invention allows a large FED to be simply manufactured.

What is claimed is:

1 1. A triode field emission display (FED) using carbon nanotubes,
2 comprising:
3 front and rear substrates disposed to face each other and separated by a
4 predetermined distance;
5 a cathode formed on the rear substrate;
6 carbon nanotubes formed on the cathode;
7 an anode formed on the front substrate;
8 phosphor formed on the anode; and
9 an extraction electrode formed on the front substrate on which the anode is
10 formed, the extraction electrode being separated from the anode by a predetermined
11 distance.

1 2. A triode field emission display (FED) using carbon nanotubes,
2 comprising:
3 front and rear substrates disposed to face each other and separated by a
4 predetermined distance;
5 cathode lines formed on the rear substrate in a striped pattern;
6 carbon nanotubes formed on the cathode lines at regular intervals;
7 anode lines formed on the front substrate in a striped pattern crossing the
8 cathode lines;
9 phosphor formed on the anode lines; and
10 extraction electrodes formed on the front substrate on which the anodes are
11 formed, each extraction electrode being separated from each adjacent anode by a
12 predetermined distance, the extraction electrodes being formed in a striped pattern
13 parallel to the anode lines.

Abstract of the Disclosure

A triode field emission display using carbon nanotubes having an excellent electron emission characteristic is provided. By forming extraction electrodes for controlling emitted electrons around an anode on a front substrate, the triode field emission display (FED) using carbon nanotubes has a simple structure like a diode FED, thereby facilitating manufacture using vapor deposition of carbon nanotubes and allowing control of anode current using extraction electrodes. Accordingly, a large FED can be simply manufactured.

FIG. 1 (PRIOR ART)

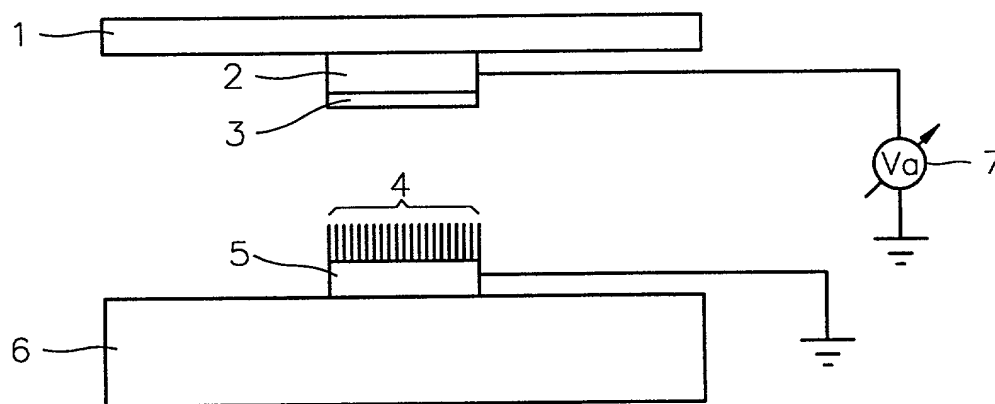


FIG. 2

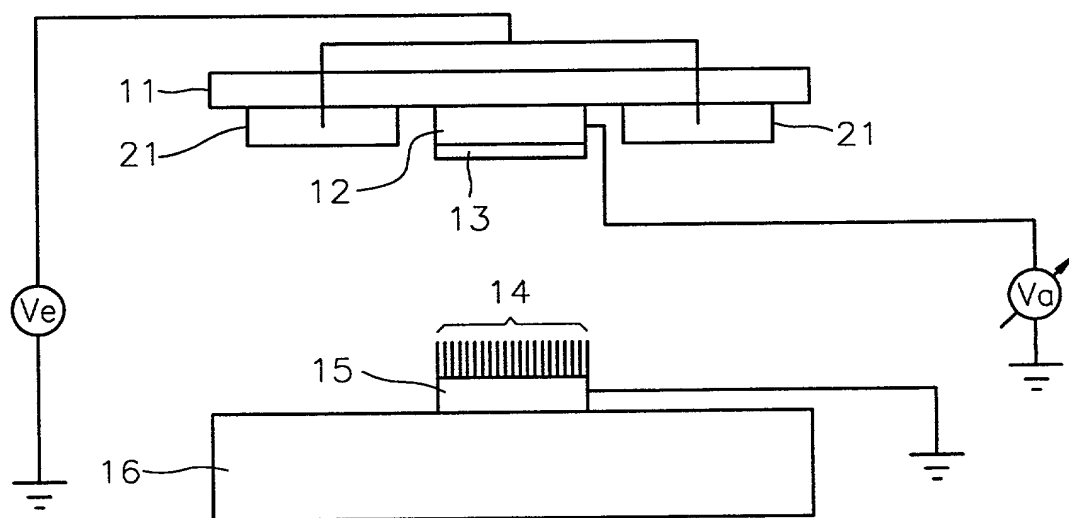


FIG. 3

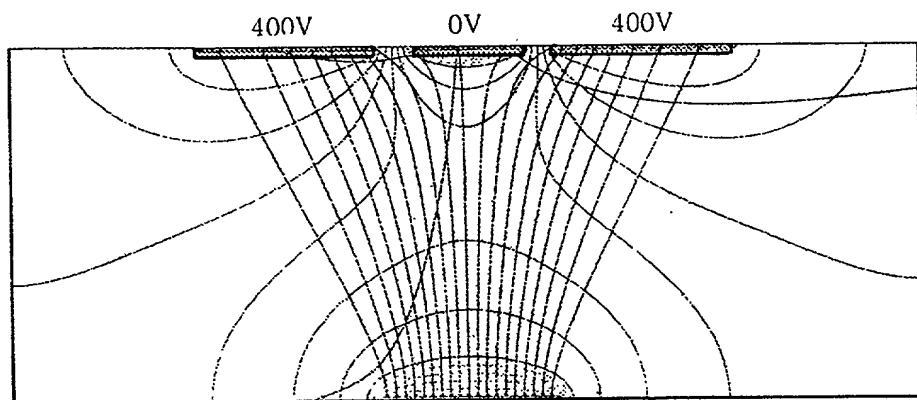


FIG. 4

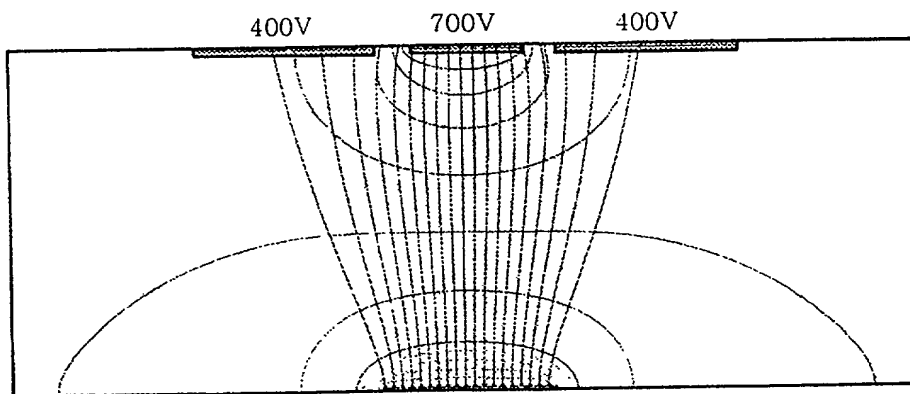
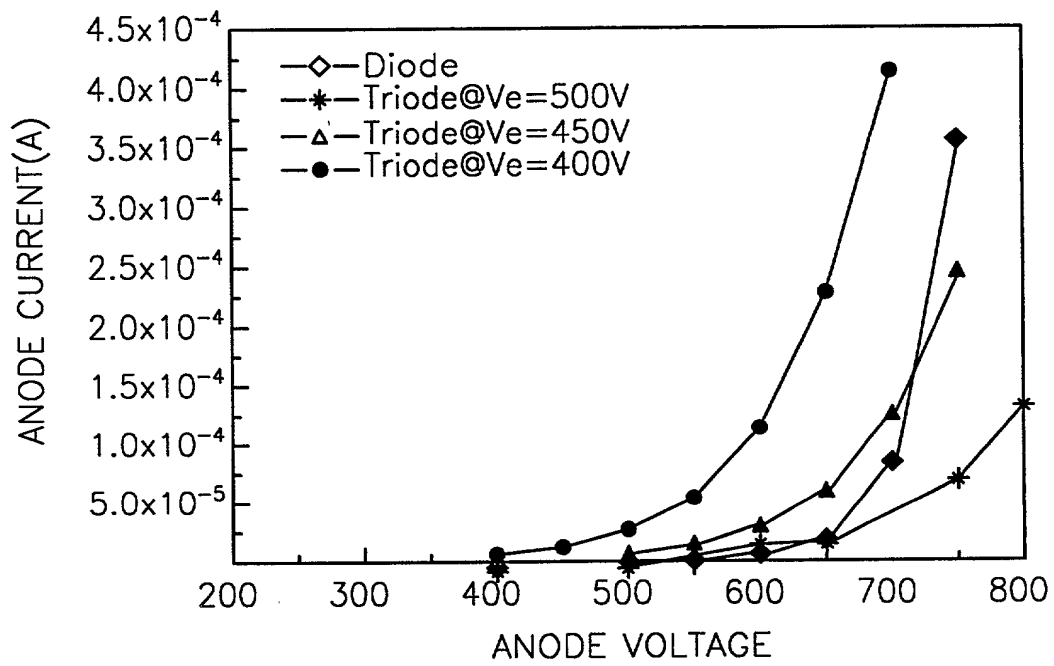


FIG. 5



**COMBINED DECLARATION AND POWER OF ATTORNEY
FOR UTILITY PATENT APPLICATION**

Attorney's Docket No.

030681-248

As a below-named inventor, I hereby declare that:

My residence, post office address and citizenship are as stated below next to my name;

I BELIEVE I AM THE ORIGINAL, FIRST AND SOLE INVENTOR (if only one name is listed below) OR AN ORIGINAL, FIRST AND JOINT INVENTOR (if more than one name is listed below) OF THE SUBJECT MATTER WHICH IS CLAIMED AND FOR WHICH A PATENT IS SOUGHT ON THE INVENTION ENTITLED:

TRIODE FIELD EMISSION DISPLAY USING CARBON NANOBUTUBES

the specification of which

(check one)

☐ is attached hereto;

☐ was filed on _____ as

Application No. _____

and was amended on _____;

(if applicable)

I HAVE REVIEWED AND UNDERSTAND THE CONTENTS OF THE ABOVE-IDENTIFIED SPECIFICATION, INCLUDING THE CLAIMS, AS AMENDED BY ANY AMENDMENT REFERRED TO ABOVE;

I ACKNOWLEDGE THE DUTY TO DISCLOSE TO THE OFFICE ALL INFORMATION KNOWN TO ME TO BE MATERIAL TO PATENTABILITY AS DEFINED IN TITLE 37, CODE OF FEDERAL REGULATIONS, Sec. 1.56 (as amended effective March 16, 1992);

I do not know and do not believe the said invention was ever known or used in the United States of America before my or our invention thereof, or patented or described in any printed publication in any country before my or our invention thereof or more than one year prior to said application; that said invention was not in public use or on sale in the United States of America more than one year prior to said application; that said invention has not been patented or made the subject of an inventor's certificate issued before the date of said application in any country foreign to the United States of America on any application filed by me or my legal representatives or assigns more than twelve months prior to said application;

I hereby claim foreign priority benefits under Title 35, United States Code Sec. 119 and/or Sec. 365 of any foreign application(s) for patent or inventor's certificate as indicated below and have also identified below any foreign application for patent or inventor's certificate on this invention having a filing date before that of the application(s) on which priority is claimed:

COMBINED DECLARATION AND POWER OF ATTORNEY			Attorney's Docket No. 030681-248	
COUNTRY/INTERNATIONAL	APPLICATION NUMBER	DATE OF FILING (day, month, year)	PRIORITY CLAIMED	
Rep. of Korea	00-9394	25/02/2000	YES X NO__	
			YES__ NO__	

I hereby appoint the following attorneys and agent(s) to prosecute said application and to transact all business in the Patent and Trademark Office connected therewith and to file, prosecute and to transact all business in connection with international applications directed to said invention:

William L. Mathis 17,337 Peter H. Smolka 15,913 Robert S. Swecker 19,885 Platon N. Mandros 22,124 Benton S. Duffett, Jr. 22,030 Joseph R. Magnone 24,239 Norman H. Stepno 22,716 Ronald L. Grudziecki 24,970 Frederick G. Michaud, Jr. 26,003 Alan E. Kopecki 25,813 Regis E. Slutter 26,999	Samuel C. Miller, III 27,360 Ralph L. Freeland, Jr. 16,110 Robert G. Mukai 28,531 George A. Hovanec, Jr. 28,223 James A. LaBarre 28,632 E. Joseph Gess 28,510 R. Danny Huntington 27,903 Eric H. Weisblatt 30,505 James W. Peterson 26,057 Teresa Stanek Rea 30,427 Robert E. Krebs 25,885	Robert M. Schulman 31,196 William C. Rowland 30,888 T. Gene Dillahunt 25,423 Patrick C. Keane 32,858 Bruce J. Boggs, Jr. 32,344 William H. Benz 25,952 Peter K. Skiff 31,917 Richard J. McGrath 29,195 Matthew L. Schneider 32,814 Michael G. Savage 32,596 Gerald F. Swiss 30,113 Charles F. Wieland III 33,096
--	--	---

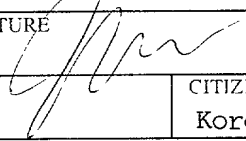
and: _____

Address all correspondence to: **Charles F. Wieland III**
BURNS, DOANE, SWECKER & MATHIS, L.L.P.
 P.O. Box 1404
 Alexandria, Virginia 22313-1404

Address all telephone calls to: Charles F. Wieland III at (703) 836-6620.

I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code and that such willful false statements may jeopardize the validity of the application or any patent issued thereon.

FULL NAME OF SOLE OR FIRST INVENTOR Hang-woo Lee	SIGNATURE <i>Hang-woo Lee</i>	DATE 21 Octber 2000
RESIDENCE Suwon-city, Kyungki-do, Rep. of Korea		CITIZENSHIP Korean
POST OFFICE ADDRESS 516-102 Jugong Apt., Youngtong-dong, Paldal-gu Suwon-city, Kyungki-do, Rep. of Korea		
FULL NAME OF SECOND JOINT INVENTOR, IF ANY Nae-sung Lee	SIGNATURE <i>Nae-sung Lee</i>	DATE 21 October 2000
RESIDENCE Seoul, Rep. of Korea		CITIZENSHIP Korean
POST OFFICE ADDRESS 241-12 Daeheung-dong, Mapo-gu, Seoul, Rep. of Korea		
FULL NAME OF THIRD JOINT INVENTOR, IF ANY Yong-soo Choi	SIGNATURE <i>Yong-soo Choi</i>	DATE 21 October 2000
RESIDENCE Seoul, Rep. of Korea		CITIZENSHIP Korean
POST OFFICE ADDRESS 296 Bongcheon 7-dong, Kwanak-gu, Seoul, Rep. of Korea		

FULL NAME OF FOURTH JOINT INVENTOR, IF ANY Jong-min Kim		SIGNATURE 		DATE 21 October 2000
RESIDENCE Seongnam-city, Kyungki-do, Rep. of Korea			CITIZENSHIP Korean	
POST OFFICE ADDRESS 305-1006 Halla Apt., Keumgok-dong, Bundang-gu Seongnam-city, Kyungki-do, Rep. of Korea				
FULL NAME OF FIFTH JOINT INVENTOR, IF ANY		SIGNATURE		DATE
RESIDENCE			CITIZENSHIP	
POST OFFICE ADDRESS				
FULL NAME OF SIXTH JOINT INVENTOR, IF ANY		SIGNATURE		DATE
RESIDENCE			CITIZENSHIP	
POST OFFICE ADDRESS				
FULL NAME OF SEVENTH JOINT INVENTOR, IF ANY		SIGNATURE		DATE
RESIDENCE			CITIZENSHIP	
POST OFFICE ADDRESS				
FULL NAME OF EIGHTH JOINT INVENTOR, IF ANY		SIGNATURE		DATE
RESIDENCE			CITIZENSHIP	
POST OFFICE ADDRESS				
FULL NAME OF NINTH JOINT INVENTOR, IF ANY		SIGNATURE		DATE
RESIDENCE			CITIZENSHIP	
POST OFFICE ADDRESS				
FULL NAME OF TENTH JOINT INVENTOR, IF ANY		SIGNATURE		DATE
RESIDENCE			CITIZENSHIP	
POST OFFICE ADDRESS				
FULL NAME OF ELEVENTH JOINT INVENTOR, IF ANY		SIGNATURE		DATE
RESIDENCE			CITIZENSHIP	
POST OFFICE ADDRESS				
FULL NAME OF TWELFTH JOINT INVENTOR, IF ANY		SIGNATURE		DATE
RESIDENCE			CITIZENSHIP	
POST OFFICE ADDRESS				